CA8160

Georgia Institute of Technology
Office of Contract Administration
OCA PAD AMENDMENT - PROJECT HEADER INFORMATION

18-JUN-1997 15:22

Document Header Id #: 40372 ACTIVE
Project #: E-20-M52 Cost share #: Rev #: 1
Center #: 10/24-6-R0162-0A0 Center shr #:
OCA file #: Project type: RES

Contract #: AGMT. DTD. 10/17/96 Mod #: LETTER DATED JUNE 1 Award type: AGR
Prime #: Contract entity: GTRC

CFDA:
PE #:

Project unit: CIVIL ENGR Unit code: 25
Project director(s):
PDPI- MARTIN C S CIVIL ENGR (404)894-2224

Sponsor : PATTERSON PUMP COMPANY/TOCCOA, GA
Division Id: 265 / 5385
Award period: 11-OCT-1996 to 31-JUL-1997 (performance) 31-JUL-1997 (reports)

Sponsor amount	New this change	Total to date
Contract value:	0.00	45,596.00
Funded:	0.00	45,596.00
Cost sharing amount:	0.00	0.00

Does subcontracting plan apply?

Title: SUMP MODEL TEST OF PUMP INTAKE STRUCTURE

PROJECT ADMINISTRATIVE DATA

OCA contact: Jacquelyn L. Bendall (404) 894-4820

Sponsor technical contact:
BOBBY RICKMAN
PATTERSON PUMP COMPANY
P. O. BOX 790
TOCCOA, GA 30577

Phone: 7068862101
Fax:
Email:

Sponsor issuing office:
BOBBY RICKMAN
PATTERSON PUMP COMPANY
P.O. BOX 790
TOCCOA, GA 30577

Phone: 7068862101
Fax:
Email:

Security class (U,C,S,TS): U
Defense priority rating : N/A

ONR resident rep is ACO (Y/N): N
Supplemental sheet: N/A

Equipment title vests with: G

Administrative comments -
Letter dated June 17, 1997 extends the period of performance through July 31, 1997.

U
(2)

PROJECT CLOSEOUT - NOTICE

Closeout Notice Date 05-NOV-1997

Project Number E-20-M52 Doch Id 40372

Center Number 10/24-6-R0162-0A0

Project Director MARTIN, C

Project Unit CIVIL ENGR

Sponsor PATTERSON PUMP COMPANY/TOCCOA, GA

Division Id 5385

Contract Number AGMT. DTD. 10/17/96 Contract Entity GTRC

Prime Contract Number

Title SUMP MODEL TEST OF PUMP INTAKE STRUCTURE

Effective Completion Date 31-JUL-1997 (Performance) 31-JUL-1997 (Reports)

Closeout Action:	Y/N	Date Submitted
Final Invoice or Copy of Final Invoice	Y	
Final Report of Inventions and/or Subcontracts	Y	
Government Property Inventory and Related Certificate	N	
Classified Material Certificate	N	
Release and Assignment	N	
Other	N	

Comments

Distribution Required:	
Project Director/Principal Investigator	Y
Research Administrative Network	Y
Accounting	Y
Research Security Department	N
Reports Coordinator	Y
Research Property Team	Y
Supply Services Department/Procurement	Y
Georgia Tech Research Corporation	Y
Project File	Y

NOTE: Final Patent Questionnaire sent to PDPI

Georgia Institute of Technology
School of Civil and Environmental Engineering

E-20-M52
1+2

October 29, 1997

FAX: (404) 894-2677

Patterson Pump Company
P. O. Box 790
Toccoa, Georgia 30577

FAX: (706) 886-0023

Attention: Mr. Jack Claxton, Chief Engineer

Subject: Intake Model Tests -- Lift Station, City of Grosse Pointe, Michigan

Gentlemen:

Enclosed are 10 copies of the final report for the subject hydraulic model study.

If there are any questions or comments please contact me.

Sincerely yours,

C. Samuel Martin
Professor

Enclosures

School of Civil and Environmental Engineering
Atlanta, Georgia 30332-0355 U.S.A.
PHONE 404•894•2201
FAX 404•894•2278

FINAL REPORT

HYDRAULIC MODEL INVESTIGATION OF PUMP LIFT STATION

CITY OF GROSSE POINT, MICHIGAN

by

C. Samuel Martin

Prepared for

PATTERSON PUMP COMPANY

Toccoa, Georgia

October 1997

School of Civil Engineering

Georgia Institute of Technology

Atlanta, Georgia 30332

FOREWORD

A hydraulic model investigation has been conducted of the Lift Station of the City of Grosse Point, Michigan. The tests were performed in the Hydraulics Laboratory of the School of Civil Engineering of the Georgia Institute of Technology under the direct supervision of Professor C. Samuel Martin.

The models were constructed in the Machine Shop of the School of Civil and Environmental Engineering under the supervision of Mr. Scott Williams and Mr. Doug Samuels. Undergraduate students Stephen Bourne, Jeffrey Roberts, and Rhett Webber were instrumental in model construction, calibration of flow meters, and initial testing of the model. The model test data were collected by Professor Martin and Mr. Samuels.

The assistance and advice given by Mr. Jack Claxton of Patterson Pump Company in the course of the investigation is gratefully acknowledged.

TABLE OF CONTENTS

ABSTRACT

A hydraulic model study of the Intake of the Pump Lift Pump Station, City of Grosse Point, Michigan, was conducted at the Hydraulics Laboratory of the School of Civil and Environmental Engineering of the Georgia Institute of Technology. The model was constructed at an undistorted scale of 1:8 and operated on the basis of the Froude Law of hydraulic modeling. Tests were conducted to determine the flow pattern entering the Wet Well and approaching each of six model pumps.

Observations of the flow pattern and the shape of the free water surface for a wide range of Wet Well water level conditions for the specified combinations of pumps operating were made at flows corresponding to 150% of design flow. In addition to observations noted regarding free surface and sub-surface activity in the Wet Well and near the Model Pumps, careful measurements were made of the swirl of water entering individual pump intakes by means of vortimeters on each siphon.

Only for limited tests were the swirl angles for water entering the model pumps (siphons) near or above the recommended Hydraulic Institute limit of 5°. In a few instances Type 1 and Type 2 vortexes were observed on the water surface of the Wet Well.

Based on numerous tests, no structural modifications of the Wet Well and its appurtenances were deemed necessary. Moreover, there was no need for shifting of any of the six pumps from their initially specified positions.

For four-pump and three-pump operation it is recommended that various combinations of running of the larger pumps be given preference because of better flow conditions than with other combinations. It is recommended that the minimum Wet Well level for single-pump operation be raised to 540 feet from 538 feet to improve flow conditions. For single-pump operation it is recommended that pump P3 be used rather than P5

Finally, it is recommended that baffle walls 3 feet high by 8 feet in length be symmetrically placed in front of Pump 1, in order to minimize effect of the dewatering recess for Pump 1 and to reduce jet action through the opening of the 45° dividing wall.

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

A hydraulic model of the Intake Structure and Six Pumps of the Lift Station of the City of Grosse Point, Michigan was built and tested in the Hydraulics Laboratory of the School of Civil and Environmental Engineering of the Georgia Institute of Technology. The Wet Well Intake Structure and model pumps (siphons) were constructed at an undistorted scale of 1:8 and operated on the basis of the Froude Law of hydraulic modeling. The model components were built using plywood, steel, and Plexiglass materials. The models was built to scale using drawings furnished by Patterson Pump Company and the consulting engineers Ayres, Lewis, Norris, and May, of Ann Arbor, Michigan for the City of Grosse Point.

MODEL

The Wet Well structure consists of a 52-foot diameter tank with water entering into its side through a 12-foot diameter pipe, as shown on the plan view depicted in Figure 1. It should be

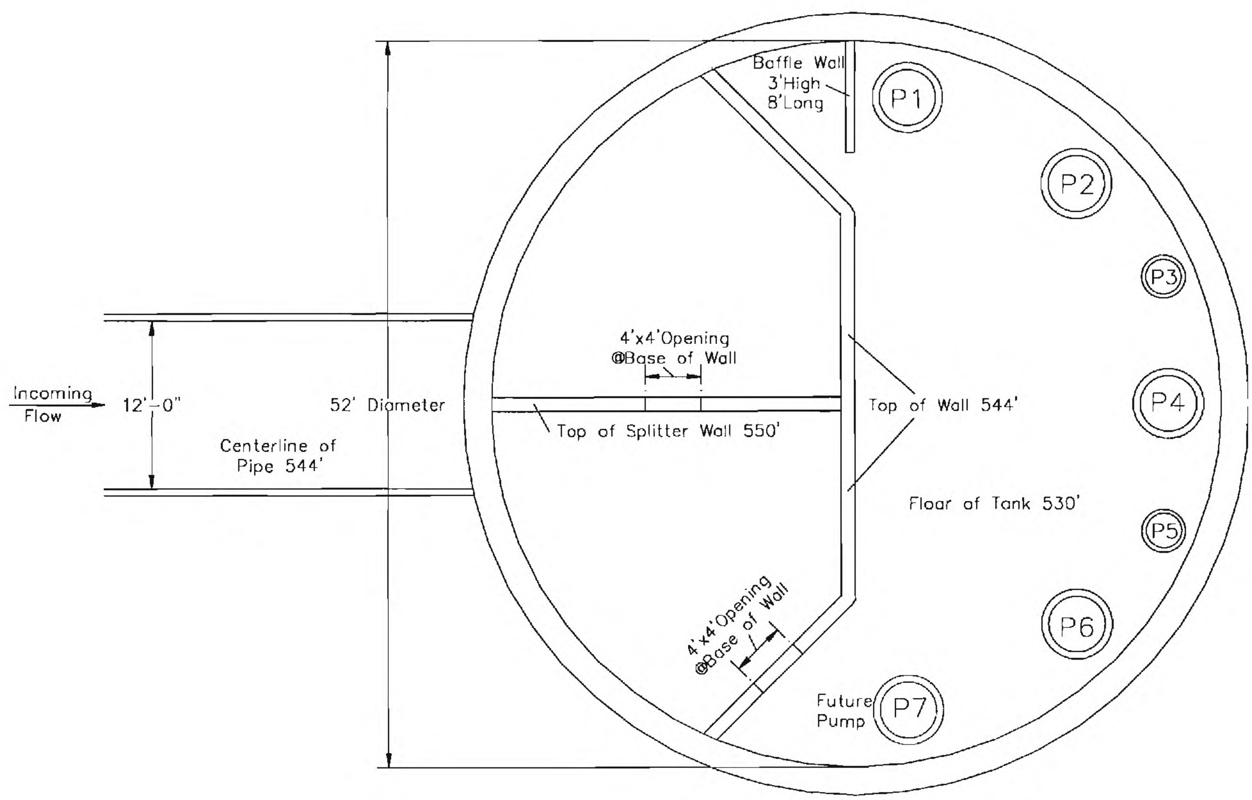


Figure 1. Plan View of Lift Station Wet Well and Location of Pumps

noted that recent design modifications altered the prototype inlet pipe diameter to 13'-8". Since the scaled velocities in the smaller model pipe are larger, it is surmised that the model results will be worse than those in the prototype.

Internals.-- In accordance with the engineers' design, a Splitter Wall was mounted from the floor of the tank (Elevation 530 ft) to the top of the inlet pipe (Elevation 550 ft). As shown in Figure 1, the elevation of the Cross Wall and Wing Walls extends from the floor to Elevation 544 feet. There are also 4 ft by 4 ft openings in both the Splitter Wall and the Wing Wall in front of Future Pump P7. To simulate the 5 ft by 5 ft by 2 ft Deep Sump Pit in front of Pump P1, a Baffle Wall 3 feet high by 8 feet long was extended from the floor of the Wet Well Tank, as shown on Figure 1.

Siphons.-- The location of the four large pumps (P1, P2, P4, and P6), and the two smaller pumps (P3 and P5) are also shown on Figure 1. The model pump bells were built to scale from Patterson Pump drawings, corresponding to 60 inches and 37 inches for the large and small pumps, respectively. Siphons were used to model the pumps rather than model pumps. By locating the model inlet tank and inlet piping well above the Hydraulics Laboratory Sump, sufficient head was established to cause a siphon action once the siphon piping was primed by means of a large vacuum tank.

HYDRAULIC MODELING LAW

For pump intake investigations the Froude Law is by far the most important in the prototype as the effects of viscosity and surface tension are considered negligible. The hydraulic model should be designed such that the effects of viscosity and surface tension do not affect its results. This is accomplished by choosing a model scale as small as possible. The Froude Law, which relates gravitational and inertial forces, yields the following expressions for length ratios and flow rate ratios between prototype and model:

Scale Ratio: $$\frac{L_P}{L_M} = \lambda$$

Head Ratio: $$\frac{H_P}{H_M} = \lambda$$

Flow Ratio: $$\frac{Q_P}{Q_M} = \lambda^{3/2}$$

For this 1:8 scale model, $\lambda = 8$, and $\lambda^{2.5} = 181$, for which $Q_P = 181Q_M$. This flow ratio was used for the setting of model flow rates, except that the flow for the simulated model pumps was in accordance with accepted practice, 150% of that dictated by the Froude Law. Therefore, the flows for the simulated pumps (siphons) were 0.00829 (150%) of the prototype values.

MEASURING EQUIPMENT

Flow Rate.-- The models consisted of a sump, siphons, distributing pipes with flow-control valves, and flow meters. The flow measuring devices used for the model were of the differential-pressure type -- elbow meters. These flow meters were calibrated *in situ* utilizing the large Weighing Tank in the Hydraulics Laboratory. The flow through each pump was determined by the use of differential air-water manometers connected to each elbow meter. Each pump effluent was measured by the elbow meters on the discharge of the model pumps in the siphon.

An empirical equation was established for each Bend Meter in terms of the model flow Q in cfs versus the differential head across the elbow Δh in inches of water. The equation has the form

$$Q = C_d\sqrt{\Delta h}$$

The actual calibration data for the four large siphons (P1, P2, P4, and P6) are plotted in Figure 2 along with the corresponding equations. Figure 3 contains the calibration data for the bend meters for small siphons P3 and P5.

Vortimeters.-- The inlet swirl into each model pump bell was determined by freely rotating vane-type vortimeters. In model units the vortimeter for the larger pump models had an inlet diameter of 3.16 inches where the cross-sectional diameter was 4.16 inches. For the vortimeters for the small pump models were 2.00 inches and 2.50 inches, respectively.

TEST PROCEDURE

The operation of the models was accomplished as follows. By submerging the discharge end of the siphon the piping was primed by means of a vacuum pump. After a few minutes the siphon would be running full, allowing the required flow to be set using control valves on each siphon.

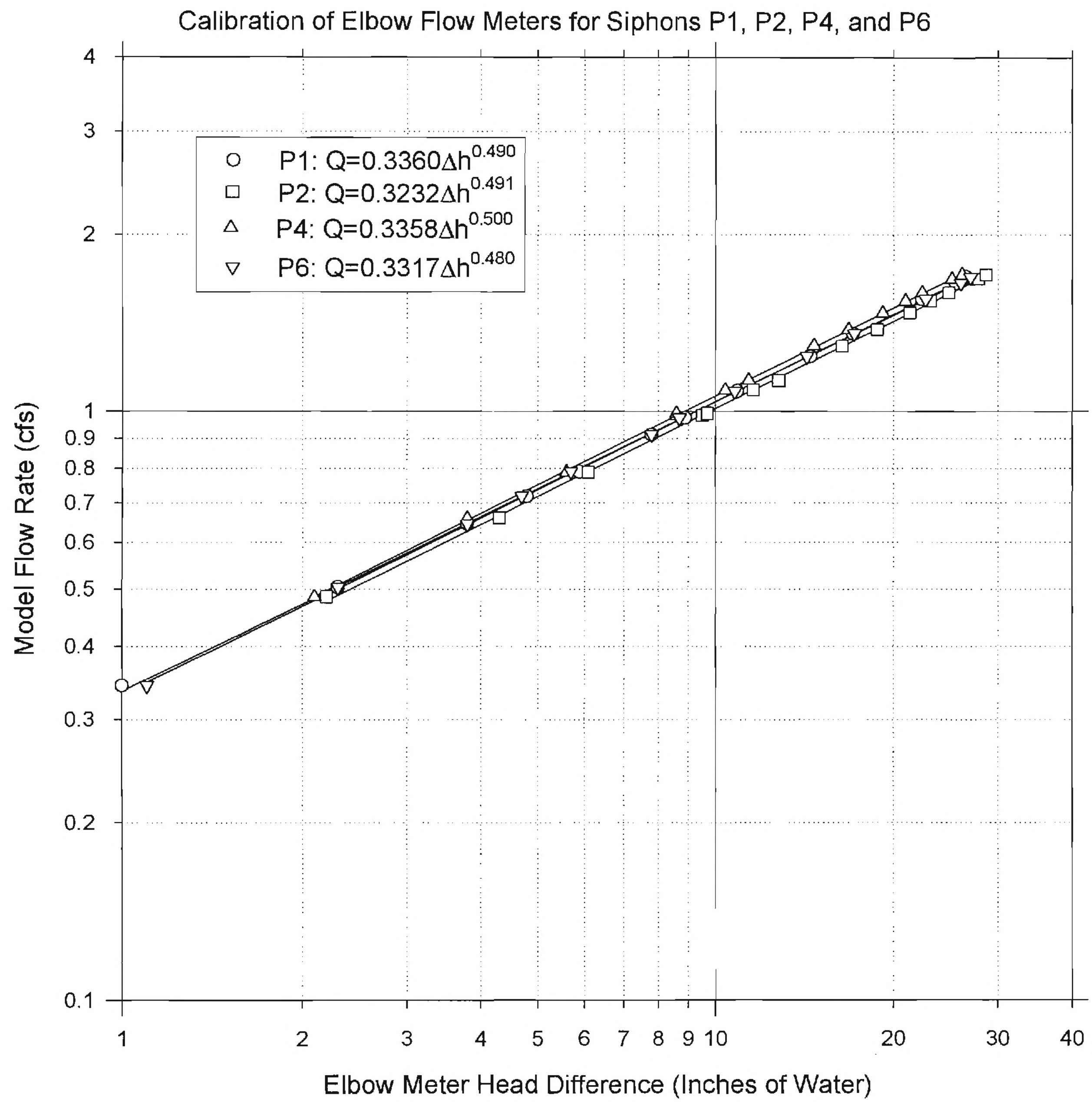


Figure 2. Bend Meter Calibration for Siphons P1, P2, P4, and P6

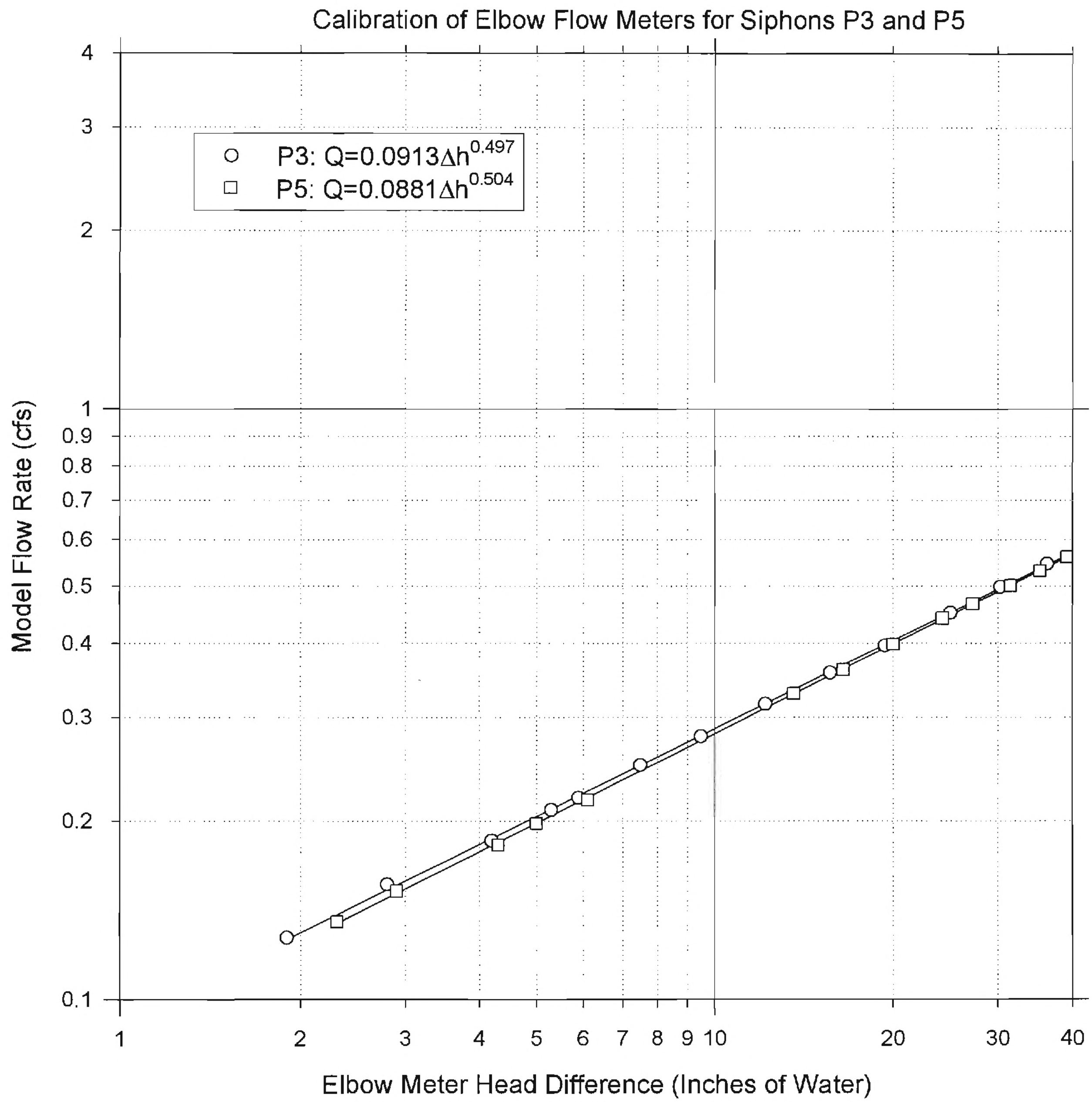


Figure 3. Bend Meter Calibration for Siphons P3 and P5

Tests were conducted to determine the flow pattern approaching the pump intake bays and within the suction channels and suction piping of each model. Observations of flow patterns were performed for the pumps operating at a full range of Wet Well intake levels. The final test program involved the measurement of the average rotational speed of each vortimeter two or three times over either a time corresponding to 20 full revolutions or, for intermittent vortimeter rotation, the number of rotations over periods of 20 to 40 seconds.

TEST PROGRAM

Before the test program was initiated, the model test flow had to be ascertained based upon the pump performance characteristics supplied by Patterson Pump Company and a knowledge of the piping system characteristics for each Wet Well water level. For Wet Well levels ranging from the lowest level of 538 feet (one small pump operating), which corresponded to the invert of the 12-foot diameter inlet piping to an elevation of 570 feet (six pumps operating). Using the pipe friction and delivery level the piping system curve was determined for Wet Well levels of 538, 544, 548, 550, 555, 560, and 570 feet, as specified by the engineers for various combinations of pumps running. Figure 4 shows the pump characteristics for the four large pumps and the system curves for the water levels 548, 550, 555, 560, and 570 feet. The intersection of the pump curves and the systems curves provides the solution for the design flow. In order to compensate for viscous effects (Reynolds number) that can not be modelled, all tests were at flows 150% of the design flows. The corresponding design point solutions for the small pump models are presented in Figure 5.

Table I provides the flows to be tested for each Wet Well level and the associated number of pumps in operation. The flows are 150% of the design values indicated on Figures 4 and 5. Table II is a summary of the settings of the differential head across each Bend Meter to be established for the test being conducted.

TEST RESULTS

The principle test results are the comments regarding observations of Wet Well water surface and sub-surface conditions and vortimeter readings for the various conditions outlined in Tables I and II. Summaries of the observations and average vortimeter speed in model units (rpm) are provided in Tables III, IV, V, and VI for six-, five-, four-, and one-three pump operation, respectively.

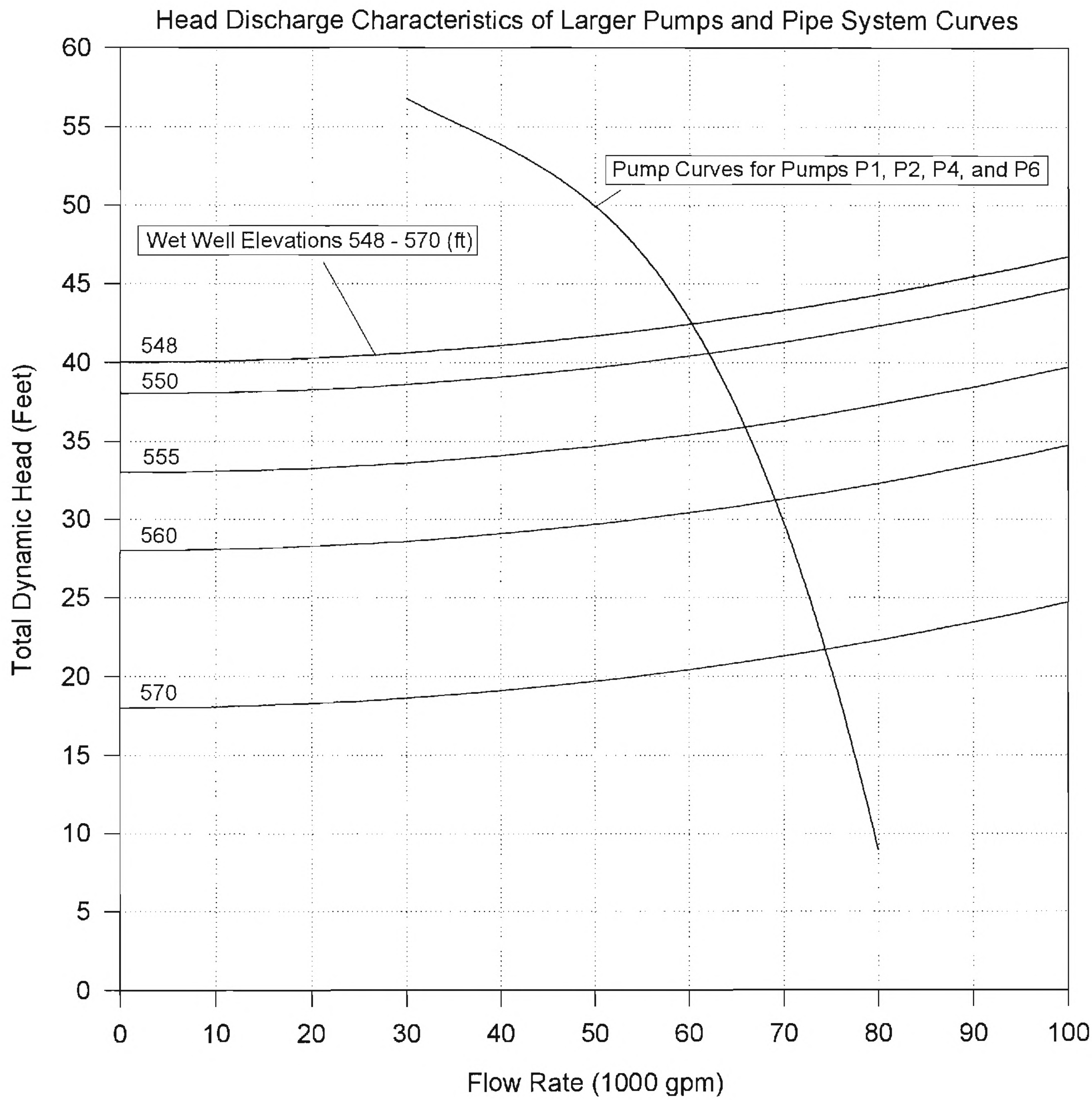


Figure 4. Piping System Curves and Pump Characteristics of Large Pumps P1, P2, P4, and P6

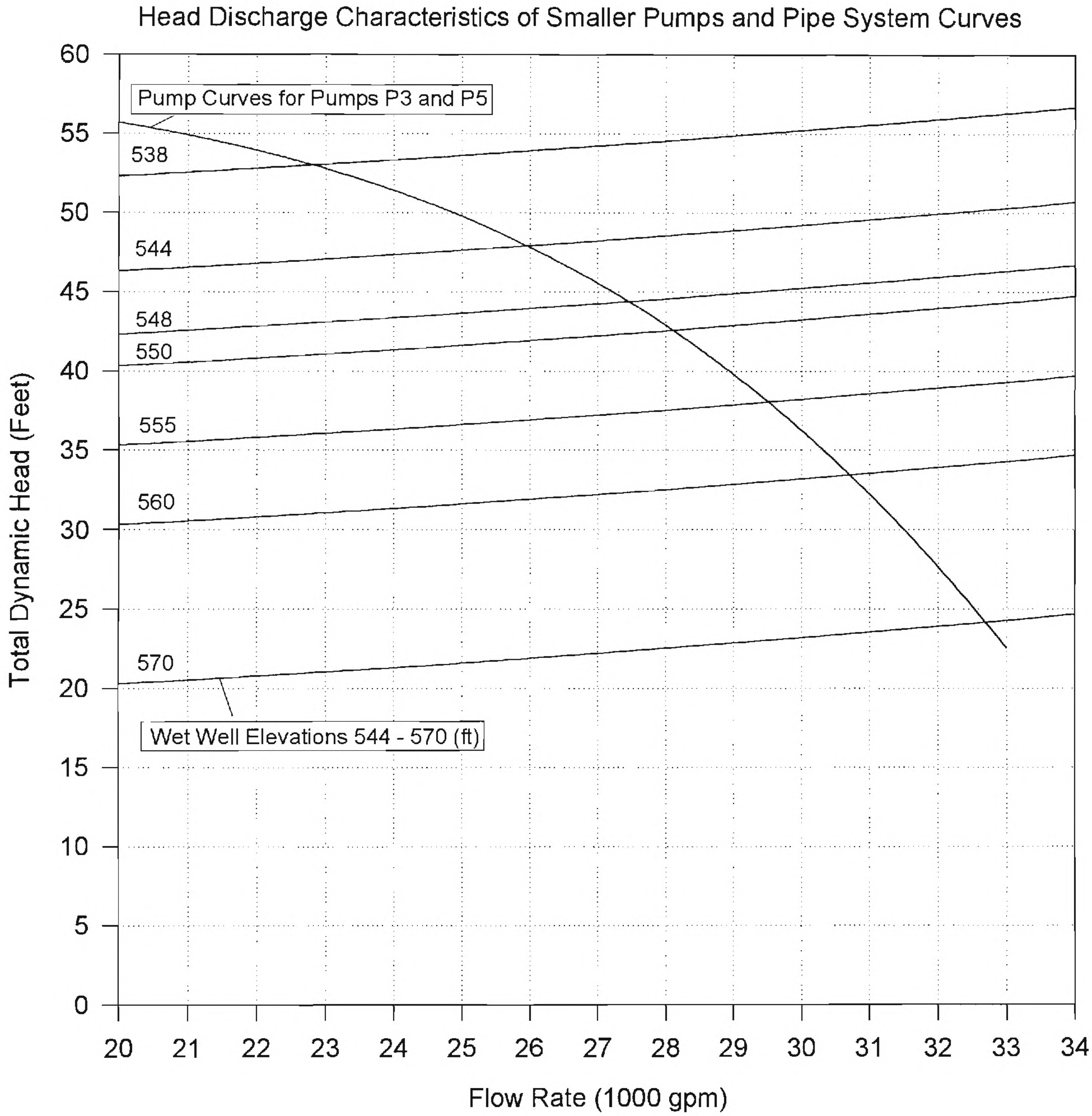


Figure 5. Piping System Curves and Pump Characteristics of Small Pumps P3 and P5

TABLE I. SEQUENCING OF PUMPS FOR VARIOUS WET WELL WATER LEVELS

Water Level Elevation (ft)	Small Pumps On		Large Pumps On		Total Flow (gpm)	150% Total Flow (gpm)
	On	Pump Flow (gpm)	On	Pump Flow (gpm)		
538	1	22,500	0	0	22,500	33,750
544	2	26,000	0	0	52,000	78,000
548	2	27,400	1	60,000	114,800	172,200
550	2	28,100	2	62,000	180,200	270,300
555	2	29,500	3	66,000	257,000	385,500
560	2	30,700	4	69,000	337,400	506,100
570	2	32,500	4	74,000	361,000	541,500

TABLE II. MANOMETER SETTINGS FOR EACH TEST

Pump	Manometer Difference in Inches at 150% Total Flow						
	Water Level in Wet Well Tank (Feet)						
	538	544	548	550	555	560	570
P1	0	0	11.4	12.2	13.9	15.2	17.5
P2	0	0	12.0	12.9	14.6	16.0	18.4
P3	21.1	28.2	31.3	32.9	36.3	39.4	44.2
P4	0	0	10.9	11.6	13.1	14.4	16.5
P5	21.7	28.9	32.0	33.7	37.1	40.2	45.0
P6	0	0	11.3	12.1	13.7	15.0	17.3

TABLE III. OBSERVATIONS FOR SIX PUMP OPERATION WITH 150% FLOW

<table>
<tr><th>Water Level Elevation (ft)</th><th>Pump Flow (gpm)</th><th>Vortimeter Rotation (rpm)</th><th>Comments</th></tr>
<tr><td rowspan="6">570</td><td>P1: Q = 111,000</td><td>[¥]P1: 86, 90 CCW</td><td rowspan="6">[¥]Swirl Angle ~ 5°

Vortimeters P1, P4 and P6 Pause

Water Surface Incoherent

Occasional Sporadic Vortex</td></tr>
<tr><td>P2: Q = 111,000</td><td>P2: 12 CW, 12 CCW</td></tr>
<tr><td>P3: Q = 48,800</td><td>P3: 7 CW, 7 CCW</td></tr>
<tr><td>P4: Q = 111,000</td><td>P4: 20 CW, 15 CCW</td></tr>
<tr><td>P5: Q = 48,800</td><td>P5: 44, 48 CW, CCW</td></tr>
<tr><td>P6: Q = 111,000</td><td>P6: 55, 57 CW</td></tr>
<tr><td rowspan="6">560</td><td>P1: Q = 103,000</td><td>P1: 21, 25 CCW</td><td rowspan="6">Vortimeters P1, P2, P3, P4 and P5 Pause and Stop

Water Surface Incoherent. Occasional Sporadic Vortex</td></tr>
<tr><td>P2: Q = 103,000</td><td>P2: 4 CW, 6 CCW</td></tr>
<tr><td>P3: Q = 46,100</td><td>P3: 4 CW, 4 CCW</td></tr>
<tr><td>P4: Q = 103,000</td><td>P4: 6 CW, 6 CCW</td></tr>
<tr><td>P5: Q = 46,100</td><td>P5: 20, 22 CW</td></tr>
<tr><td>P6: Q = 103,000</td><td>P6: 25, 26 CCW</td></tr>
</table>

TABLE IV. OBSERVATIONS FOR FIVE PUMP OPERATION WITH 150% FLOW

Water Level Elevation (ft)	Pump Flow (gpm)	Vortimeter Rotation (rpm)	Comments
555	P1: Q = 99,000 P2: Q = 99,000 P3: Q = 44,300 P4: Q = 99,000 P5: Q = 44,300	**¥P1: 85, 108 CCW** P2: 5, 12 CW P3: 10, 12 CCW P4: 18, 24 CW P5: 28, 32 CW	**¥Swirl Angle 5° - 6°** Water Surface Incoherent Occasional Sporadic Vortex
555	P1: Q = 99,000 P2: Q = 99,000 P3: Q = 44,300 P5: Q = 44,300 P6: Q = 99,000	**¥P1: 40, 80 CCW** P2: 1 CW, 2 CCW P3: 3 CW, 3 CCW P5: 39 CW, 41 CCW P6: 28, 32 CCW	**¥Swirl Angle → 5°** Vortimeters P1 and P6 Pause
555	P1: Q = 99,000 P3: Q = 44,300 P4: Q = 99,000 P5: Q = 44,300 P6: Q = 99,000	P1: 9, 9 CCW P3: 0, 3, 6 CCW P4: 3 CW, 3 CCW P5: 26, 33 CW P6: 32, 35 CCW	P1 Improved Vortimeter Activity at P5 and P6
555	P2: Q = 99,000 P3: Q = 44,300 P4: Q = 99,000 P5: Q = 44,300 P6: Q = 99,000	P2: 6, 12, 18 CCW P3: 6 CW, 3 CCW P4: 12, 15 CW P5: 14, 19 CW P6: 27, 30 CCW	Conditions Improved

TABLE V. OBSERVATIONS FOR FOUR PUMP OPERATION WITH 150% FLOW

Water Level Elevation (ft)	Pump Flow (gpm)	Vortimeter Rotation (rpm)	Comments
550	P1: Q = 93,000 P2: Q = 93,000 P3: Q = 42,200 P5: Q = 42,200	P1: 16 CW, 4 CCW **[¥]P2: 67, 80 CCW** P3: 12 CW, 12 CCW P5: 20, 25 CCW	Sporadic Type 1 Vortex Near P1 & P2 **[¥]Swirl Angle ~ 5°** Dimple Behind P4
550	P1: Q = 93,000 P3: Q = 42,200 P4: Q = 93,000 P5: Q = 42,200	P1: 12, 36, 42 CCW P3: 18, 24 CCW P4: 21, 30 CW P5: 6, 8 CW	Rough WS Behind P2. Type 2 Vortex Between P1 & P2
550	P1: Q = 93,000 P3: Q = 42,200 P5: Q = 42,200 P6: Q = 93,000	P1: 24, 38 CCW P3: 3 CW, 3 CCW P5: 8, 12 CW P6: 22, 24 CCW	Intermittent Type 2 Vortex
550	P2: Q = 93,000 P3: Q = 42,200 P4: Q = 93,000 P5: Q = 42,200	P2: 3, 12, 12 CCW P3: 18, 24 CCW P4: 21, 42, 47 CW P5: 12, 15 CCW	No Type 2 Vortex
550	P2: Q = 93,000 P3: Q = 42,200 P5: Q = 42,200 P6: Q = 93,000	P2: 21, 24 CW P3: 6, 12 CCW P5: 9, 12 CW P6: 14, 19 CCW	No Type 2 Vortex
550	P3: Q = 93,000 P4: Q = 42,200 P5: Q = 93,000 P6: Q = 42,200	P3: 12, 12 CCW **[¥]P4: 66, 72 CCW** P5: 28, 33 CW P6: 9, 15 CW	Free Surface Incoherent **[¥]Swirl Angle > 5°** Intermittent Type 2 Vortex Near P6

TABLE VI. OBSERVATIONS FOR ONE-THREE PUMP OPERATION WITH 150% FLOW

Water Level Elevation (ft)	Pump Flow (gpm)	Vortimeter Rotation (rpm)	Comments
548	P1: Q = 90,000 P3: Q = 41,100 P5: Q = 41,100	P1: 24, 30 CCW P3: 6, 6 CCW P5: 3 CW, 3 CCW	
548	P2: Q = 90,000 P3: Q = 41,100 P5: Q = 41,100	P2: 3, 3 CCW P3: 2 CW, 2 CCW P5: 14 CW, 17 CCW	
548	P3: Q = 41,100 P4: Q = 90,000 P5: Q = 41,100	**¥P3: 36, 60 CCW** P4: 33, 36 CCW **¥P5: 57, 70 CW**	**¥Swirl Angle → 3°** Sporadic Vortex Activity **¥Swirl Angle → 4°**
548	P3: Q = 41,100 P5: Q = 41,100 P6: Q = 90,000	P3: 9, 12 CCW P5: 32 CW, 36 CCW P6: 6, 9 CW	Same as P1 - P2
544	P3: Q = 39,000 P5: Q = 39,000	**¥P3: 96, 104 CW** **¥P5: 71, 80 CW**	**¥Swirl Angle → 5°** **¥Swirl Angle → 4°** P3 Regular, P5 Pauses Very Small Dimples. Type 1 &2 Vortexes
538	P3: Q = 33,800	P3: 12 CW, 12 CCW	
538	P5: Q = 33,800	**¥P5: 60, 100 CCW**	**¥Swirl Angle → 5°** Vortices at P6. Quiet Around P5

Swirl Angle.-- The vortimeter recordings in model speed N (rpm) for the specified flow rate were used to calculate a swirl angle, as follows. In model units the tip speed of the vortimeter at its inlet can be expressed

$$U = \frac{\omega D_v}{2} = \frac{\pi N D_v}{60}$$

where D_v is the diameter of the vortimeter. The mean flow velocity at the vortimeter inlet where the flow passage diameter is D is

$$V = \frac{Q}{A} = \frac{4Q}{\pi D^2}$$

The ratio of U/V becomes

$$\frac{U}{V} = \frac{\pi^2 N D_v D^2}{240Q}$$

Converting the flow rate in model units of flow Q_M (cfs) to prototype units Q_P (gpm) the swirl angle is

$$\alpha = \tan^{-1}\left(\frac{U}{V}\right) = \frac{3342 N D_v D^2}{Q_P}$$

For the large siphons for which D_v = 3.16 inches and D = 4.16 inches

$$\alpha = \tan^{-1}\left(\frac{U}{V}\right) = \frac{106N}{Q_P}$$

For the smaller siphons

$$\alpha = \tan^{-1}\left(\frac{U}{V}\right) = \frac{32N}{Q_P}$$

OBSERVATIONS

Six-Pump Operation.-- In addition to the data and comments summarized in Table III, Figure 6 is included to illustrated the sense and magnitude of the vortimeters for the set of data at 150% of design flow. For six-pump operation at Wet Well of 570 feet, Table III and Figure 6 show model vortimeter speeds up to 90 rpm for Pump P1, corresponding to a swirl angle α

approximately 5° using the above equations for swirl with N = 90 rpm and Q_P = 111,000 gpm. For this test there was sporadic vortex action leading to intermittent vortimeter motion, as shown in Table III. The vortimeters P2, P3, P4, and P6 would pause or completely come to rest momentarily. Although the water surface was incoherent there were no vortexes of Types 1 - 6 as defined by the Hydraulic Institute. For Wet Water level of 560 feet, the activity was similar, although vortimeter rotation was less than at level 570 feet, as indicated in Table III and Figure 6.

Five-Pump Operation.-- As shown by Table IV and Figures 7a and 7b, the observations for the four combinations of five-pump operation -- three large pumps and two small pumps at Wet Water level of 555 feet, were similar to those for six-pump operation. For two configurations of large pumps P1, P2, and P4 and P1, P2, and P6, the swirl angle for Pump P1 reached and exceeded 5°. There were no Type 1 or Type 2 vortexes.

Four-Pump Operation.-- There were six combinations of four-pump operation; that is, two large pumps and two small pumps for Wet Well level of 550 feet. Vortimeter speeds and observations of free and sub-surface activity and vortex formation are listed in Table V. Figures 8a, 8b, and 8c illustrate the sense and magnitude of the average vortimeter motion. As shown in Table V Type 1 vortexes (coherent surface swirl without dimples) occurred for tests with pumps P1, P2, P3, and P5, while for some other tests Type 2 vortexes -- surface dimple and coherent swirl on water surface were apparent.

Based upon qualitative observations and vortimeter readings the combinations of two large pump running for four-pump operation yielded the following conclusions

Pumps	*Figure*	*Rating*
P1 - P2	8a	Worst
P1 - P4	8a	Medium
P1 - P6	8b	Medium
P2 - P4	8b	Best
P2 - P6	8c	Best
P4 - P6	8c	Worst

Based on the these observations, combinations of running pumps P1 and P2 or P4 and P6 yield worse conditions than running other combinations of two large pumps with the smaller pumps P3 and P5 at four-pump operation.

Three-Pump Operation.-- This condition is represented by the combination of a single large pump with smaller Pumps P3 and P5 at Wet Well level of 548 feet. The four combinations are listed in Table VI and the vortimeter magnitude and directions are plotted in Figures 9a and 9b. Somewhat surprising, the entirely symmetric combination of Pumps P3, P4, and P5 running simultaneously yielded the most vortex action on the water surface and the highest swirl angles for the small pumps. The running of either pump P2 or P6 along with Pumps P3 and P5 resulted in the most favorable flow condition.

Two-Pump Operation.-- The data for this configuration of only the two small pumps running at Wet Well set at elevation 544 feet is tabulated in Table VI and plotted in Figure 10. The data show the occurrence of Types 1 and 2 vortexes as well as swirl angles up to 5°.

One-Pump Operation.-- For the operation of only one small pump, the best performance is with P3 instead of P5, apparently associated with the opening in the Wing Wall near future Pump P7. It should be pointed out that the flow condition is quite rough inasmuch as this level is the same as the invert of the inlet pipe in the model. For the prototype the larger inlet pipe diameter of 13'-8" with the same centerline elevation and a corresponding lower invert may improve the flow conditions. It is recommended, however, that the minimum level for single pump operation at low flows be raised to 540 feet.

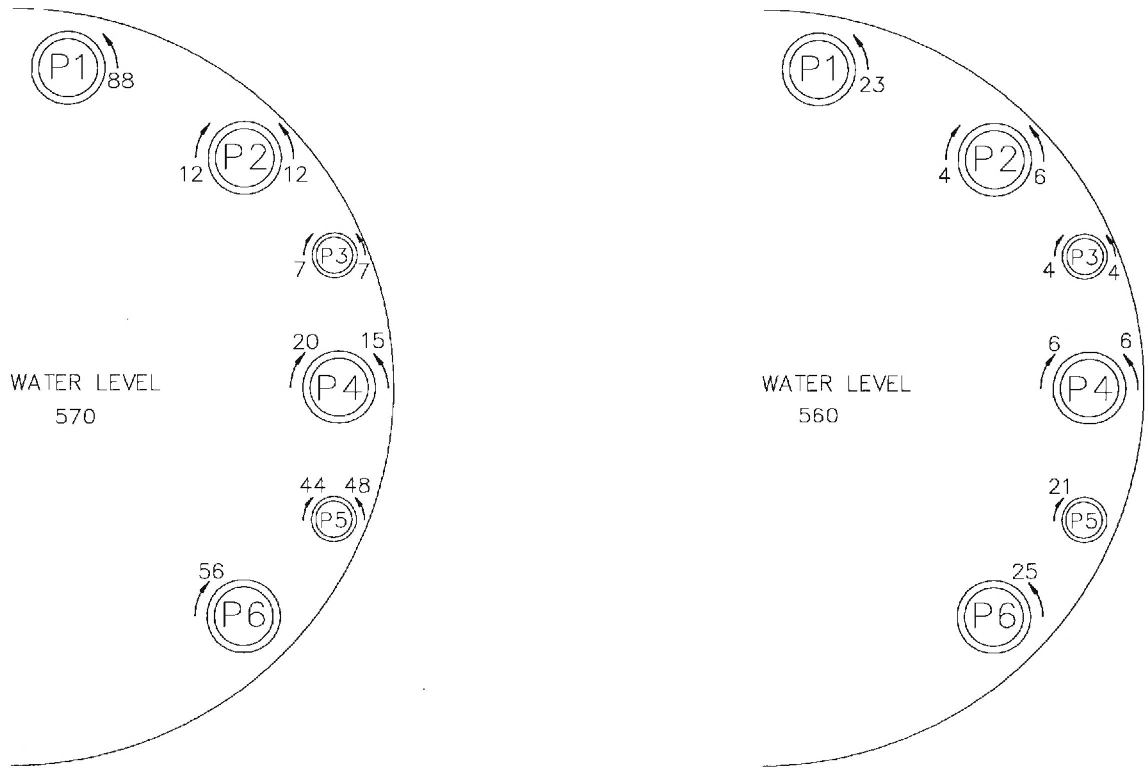


Figure 6. Vortimeter Readings in Model Units (rpm) for Six Pump Operation

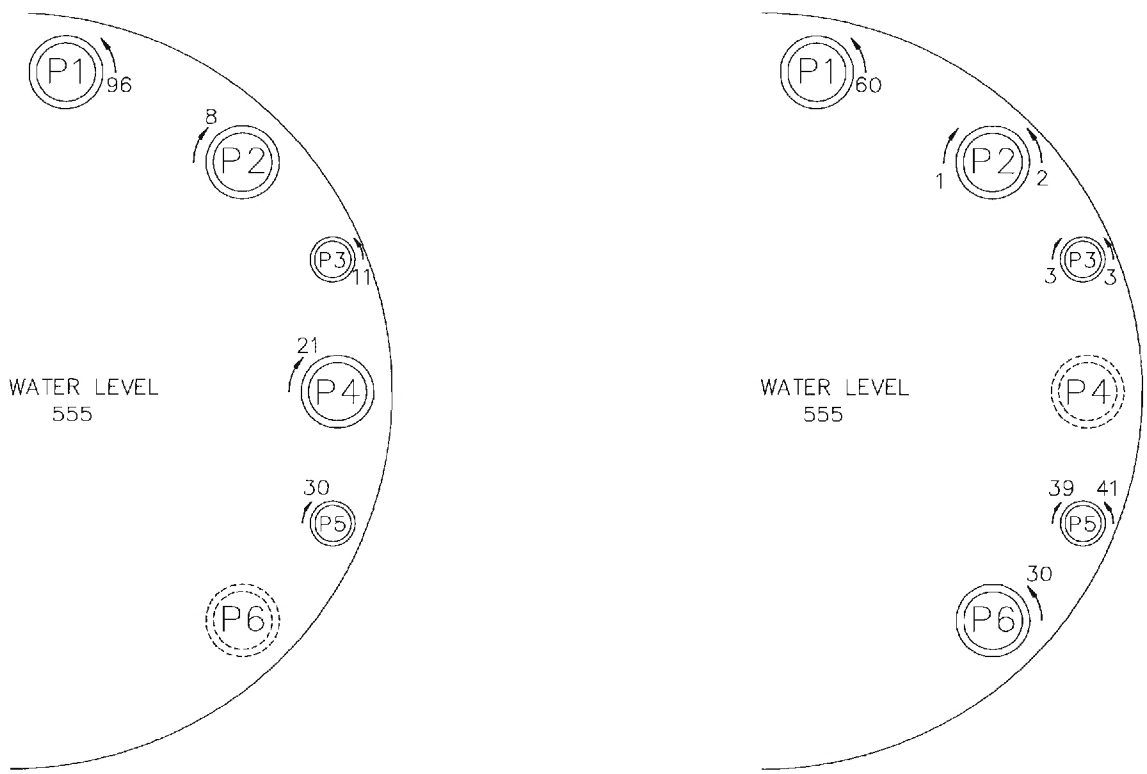


Figure 7a. Vortimeter Readings in Model Units (rpm) for Five Pump Operation

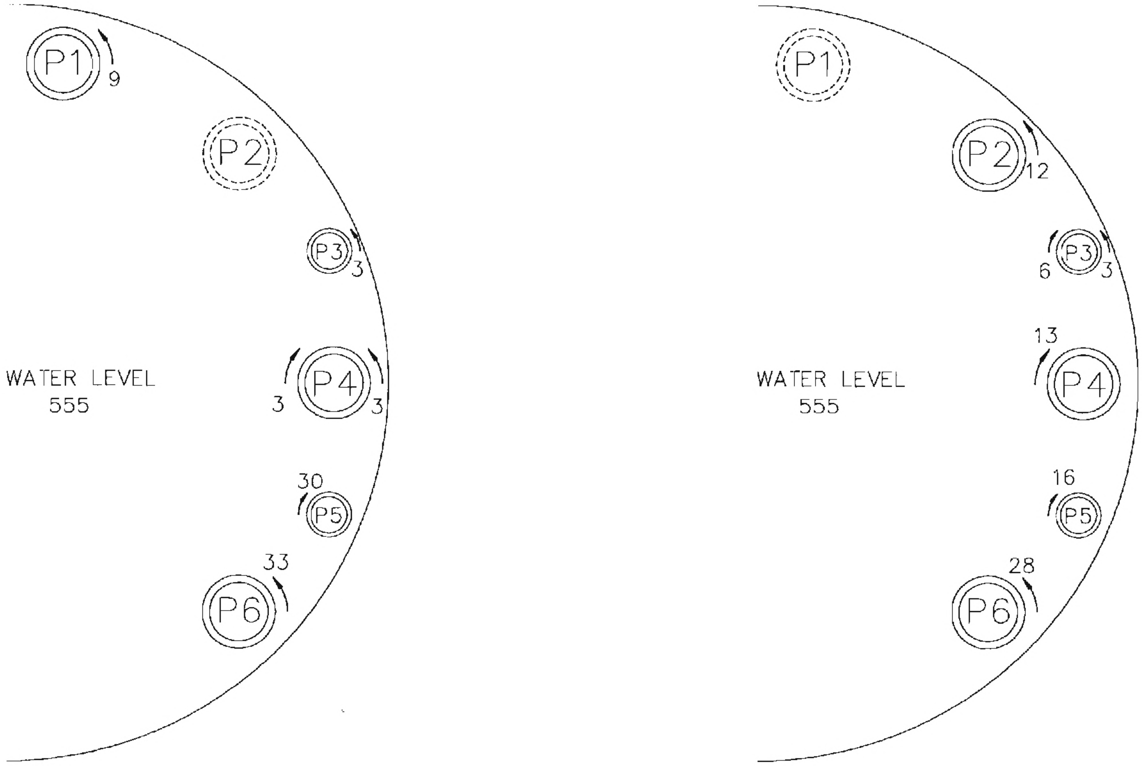


Figure 7b. Vortimeter Readings in Model Units (rpm) for Five Pump Operation

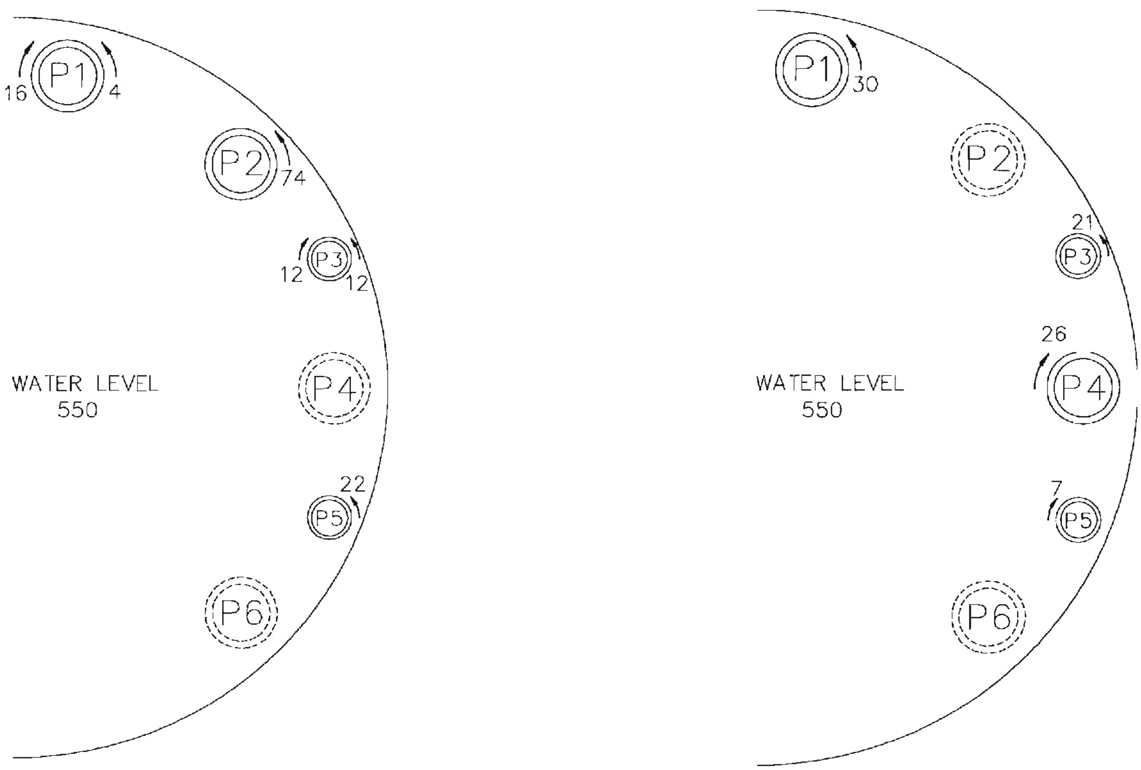


Figure 8a. Vortimeter Readings in Model Units (rpm) for Four Pump Operation

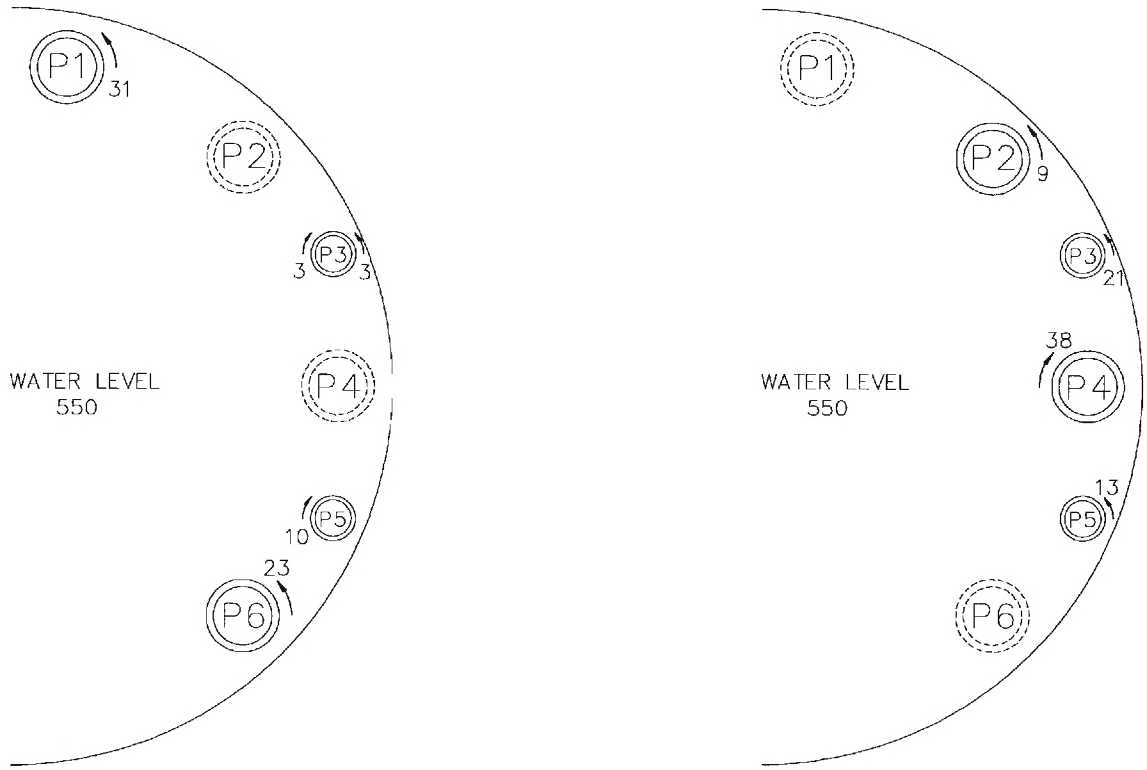


Figure 8b. Vortimeter Readings in Model Units (rpm) for Four Pump Operation

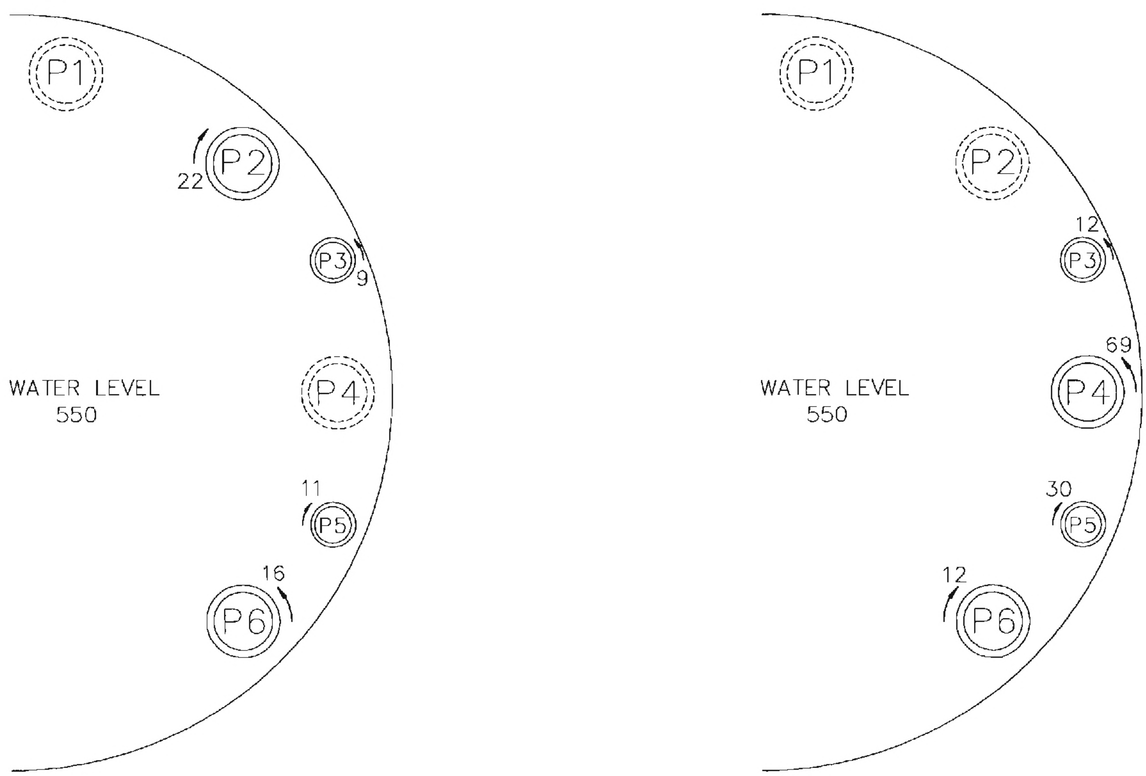


Figure 8c. Vortimeter Readings in Model Units (rpm) for Four Pump Operation

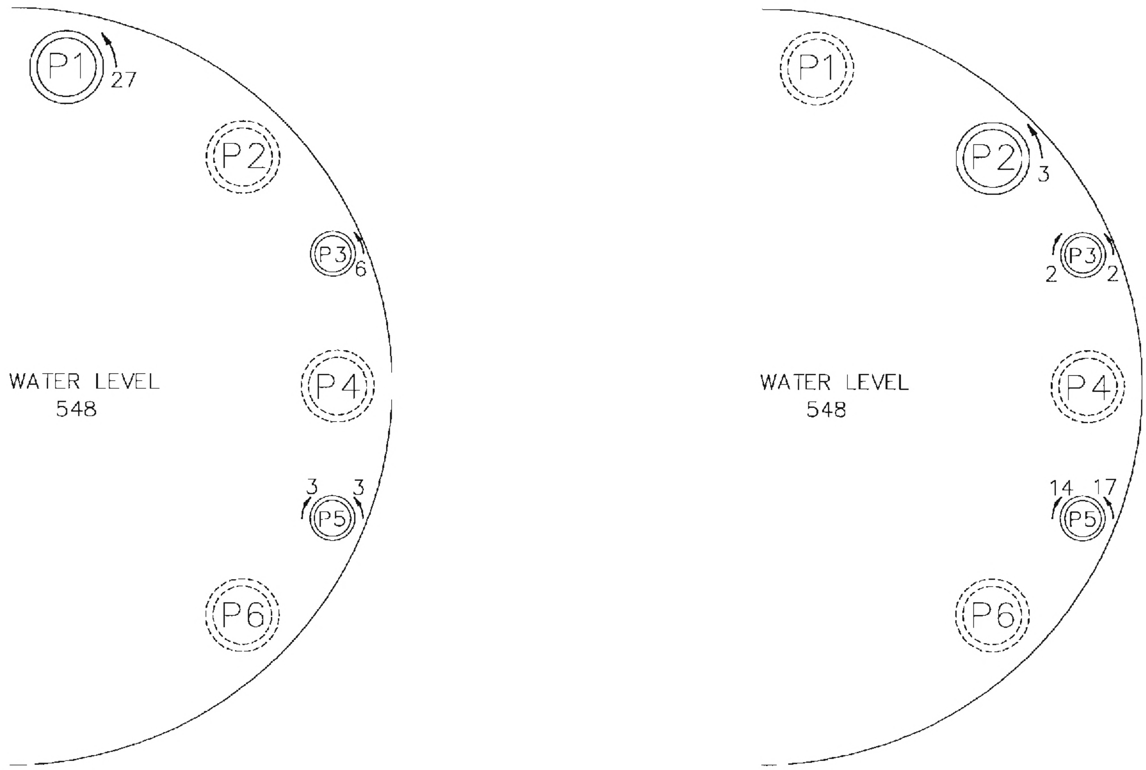


Figure 9a. Vortimeter Readings in Model Units (rpm) for Three Pump Operation

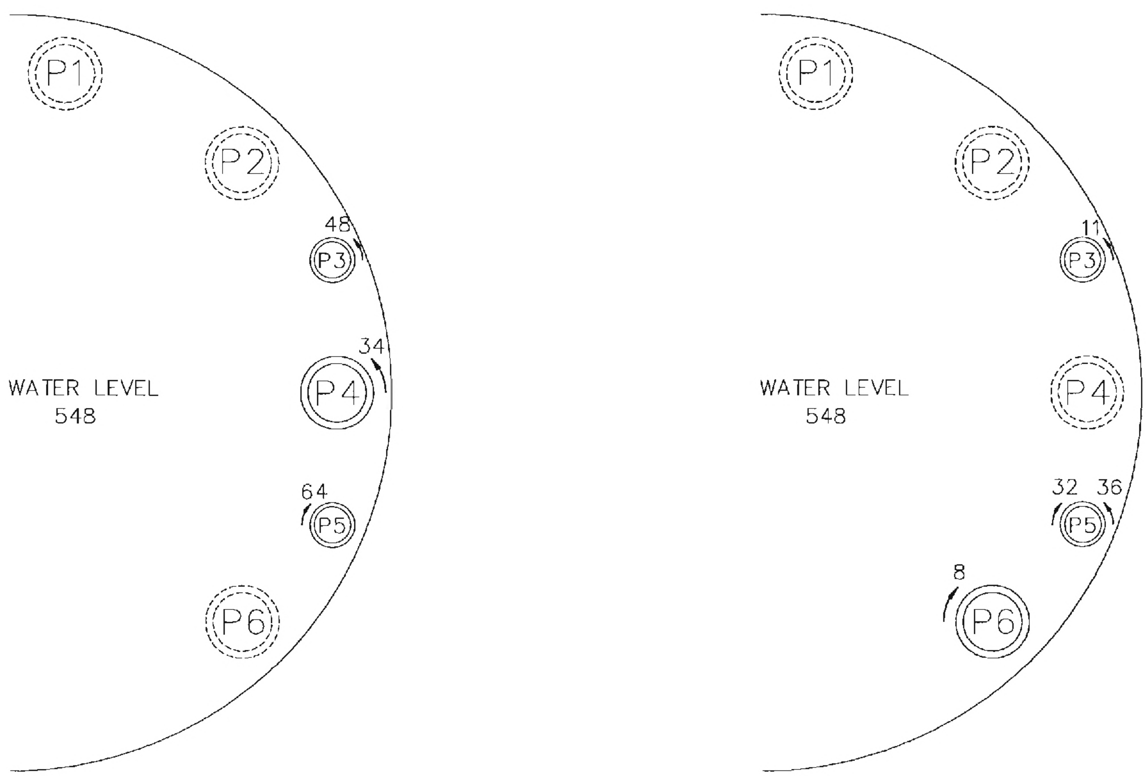


Figure 9b. Vortimeter Readings in Model Units (rpm) for Three Pump Operation

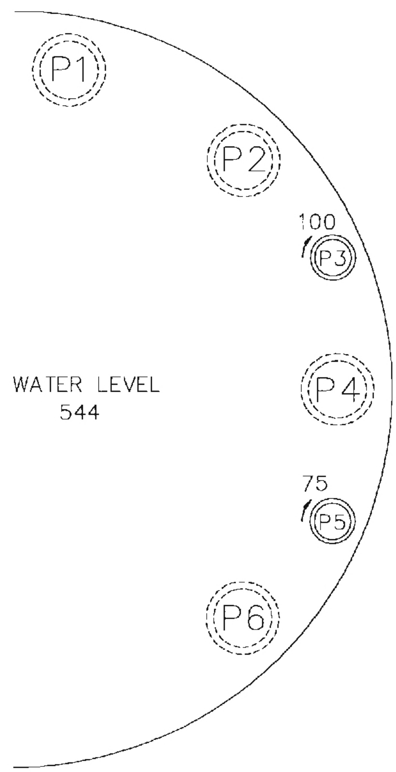
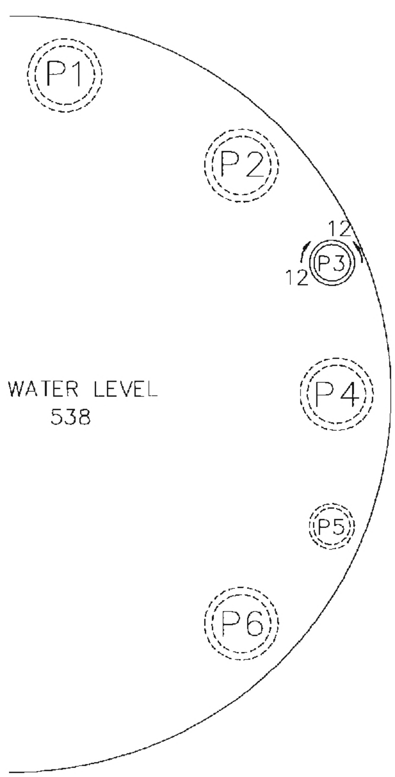


Figure 10. Vortimeter Readings in Model Units (rpm) for Two Pump Operation



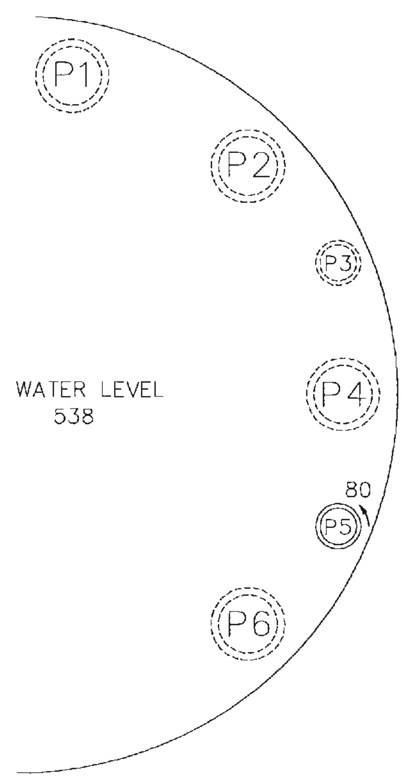


Figure 11. Vortimeter Readings in Model Units (rpm) for One Pump Operation

CONCLUSIONS AND RECOMMENDATIONS

- No structural modifications are needed to the Wet Well Tank nor its internals
- There is no need to shift or alter the location of any of the six pumps
- The increase in inlet piping diameter from that tested in the model (12') to (13'-8") should improve flow conditions due to lower velocities
- Although both Type 1 vortex (coherent surface swirl without dimples) and Type 2 vortex (surface dimple and coherent swirl at water surface) occurred for certain tests with four pumps operating or less, vortex activity was not consistent
- Type 3 - 6 vortexes which are characterized by more severe activity, and often extending from the water surface to the pump, were not observed
- For four-pump operation (Elevation 550 - 555) it is recommended that two larger pump combinations of P1 and P4, P1 and P6, P2 and P4, or P2 and P6 be given preference because of better flow conditions than P1 and P2 or P4 and P6
- For three-pump operation (Elevation 548 - 550) it is recommended that Pump P2 or P6 be selected rather than Pump P1 or P4
- It is recommended that the minimum Wet Well level for pumping under single-pumping operation be raised to 540 feet from 538 feet to improve flow conditions
- For single-pump operation (Elevation 540 - 544) it is recommended that pump P3 be used rather than P5